BASIC RESEARCH IN PRECISE MEASUREMENT

APPENDIX C

FINAL REPORT

FOR

TASK 3- FILM STABILITY ON MEASURING DEVICES

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ABSTRACT

A Gilliland Measuring Engine has been modified to allow experimental measurements to be made on the relationship between the radient energy incident on a photographic film and the air flow rate required to cool the film sufficiently for precise measurement. This report describes the test set up and presents the experimental results.

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1. INTRODUCTION

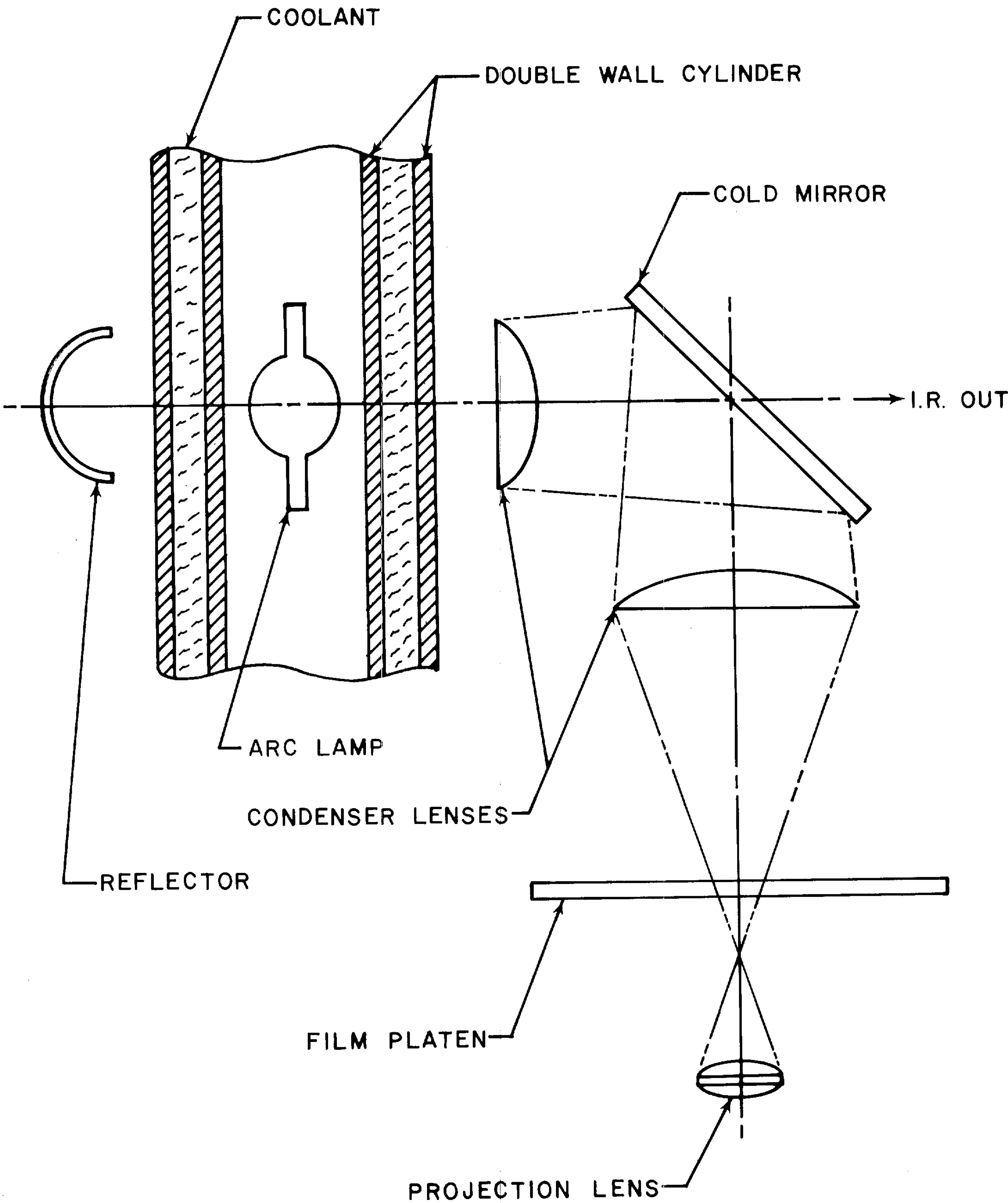
In principle, there are many forces which can act on a piece of photographic film in a measuring instrument to cause distortions and, therefore, measurement errors. In practice, a good many of these potential sources of error are reduced to negligible quantities by good instrument design and proper area environmental control. Film stretch caused by excessive tension in film transports is generally controlled by good transport design or eliminated entirely by the use of cut film or chips. Humidity control of the mensuration area is generally considered a necessity and is therefore provided.

The major problem which cannot be eliminated by design is the heating effect caused by absorption of the viewing light which passes through the film. This problem is a rather small one in instruments designed solely for manual measurements at low to medium magnifications. It becomes a major problem in instruments which are designed for high magnification and/or image correlation using image disectors. In this latter case, the light intensity may not only be quite high, but might also be variable as a function of magnification. In addition, the amount of energy which is absorbed in the emulsion and converted into heat is a function of the film density, and is, therefore, a variable.

To put the problem in some perspective, it should be noted that the lamps in manual instruments, such as the Mann engine, are usually rated at one to five watts. After accounting for light losses in the condenser system, lamp efficiencies, and removal of the infra-red components by filtering, the actual amount of light power impinging on the film is probably in the milliwatt range. In contrast to this, measuring projector systems and systems employing image correlation and viewing frequently use arc lamps rated between 400 watts and 4 kilowatts. With these lamps it is possible to have several watts of light energy impinging on the film, even after great care has been taken to remove all the IR components. If this energy is focused onto a small area, the energy density can quickly become high enough to completely destroy the film unless measures are taken to remove the heat.

2. QUANTITATIVE TEST PROGRAM

In order to obtain some quantitative data, a series of tests was run using the Gilliland measuring projector. This instrument is equipped with a 1000 watt mercury arc lamp. Figure 1 is a schematic diagram of the lamp-condenser assembly showing the major components. The arc lamp is operated inside a double wall cylinder which contains a mineral oil coolant. The mineral oil is quite transparent in the visible but strongly absorbs ultra-violet and infra-red energy. The condenser lenses collect the light energy and concentrate it in a circular area on the film platen which normally has a diameter of about two inches.



GILLILAND LENS SYSTEM

FIGURE I

Calculations as to lamp efficiencies, optical efficiencies, and losses are very difficult to perform with any high degree of accuracy. In addition, lamp output tends to vary as a function of time as the lamp ages.

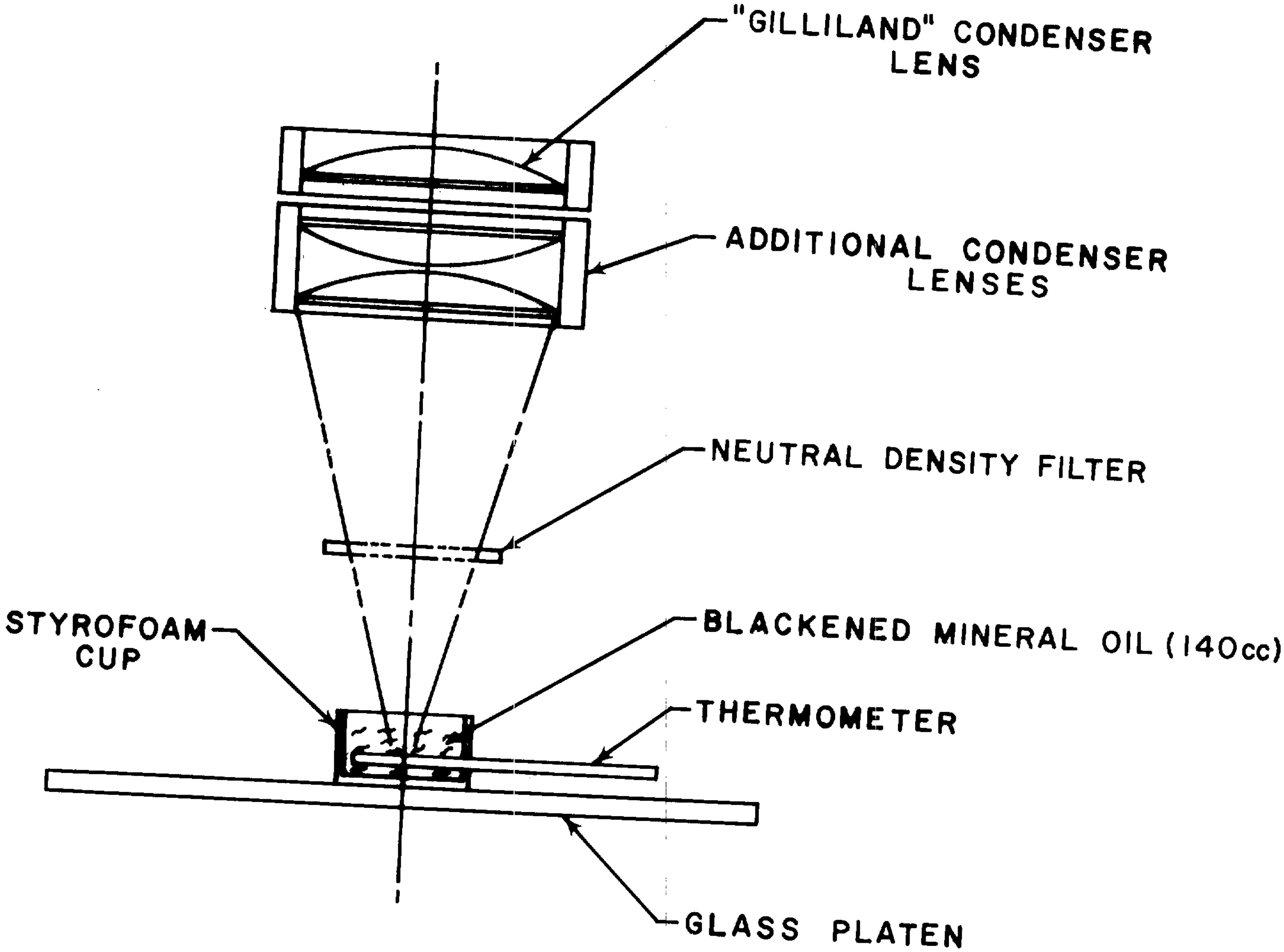
In order to overcome these difficulties, it was decided to calibrate the illumination system by actually measuring the incident energy at the film plane. Figure 2 shows the test setup which was used. In order to simulate the conditions of some of the newer instruments, additional condenser lenses were added to concentrate the light onto a smaller area. The net result was that the energy was concentrated into a spot with a 0.75 inch diameter at the film plane. The total energy was measured by use of a calorimeter in which the temperature rise in a measured quantity of blackened mineral oil was measured as a function of time. Neutral density filters were placed in the light path, so that several values of energy density at the film plane could be obtained. Table 1 shows the light power obtained for the various filters.

Table 1

Filter	Light Power - Watts
0	8.48
0.1	5.85
0.2	4.46
0.3	3.57
0.4	2.23
0.5	1.80

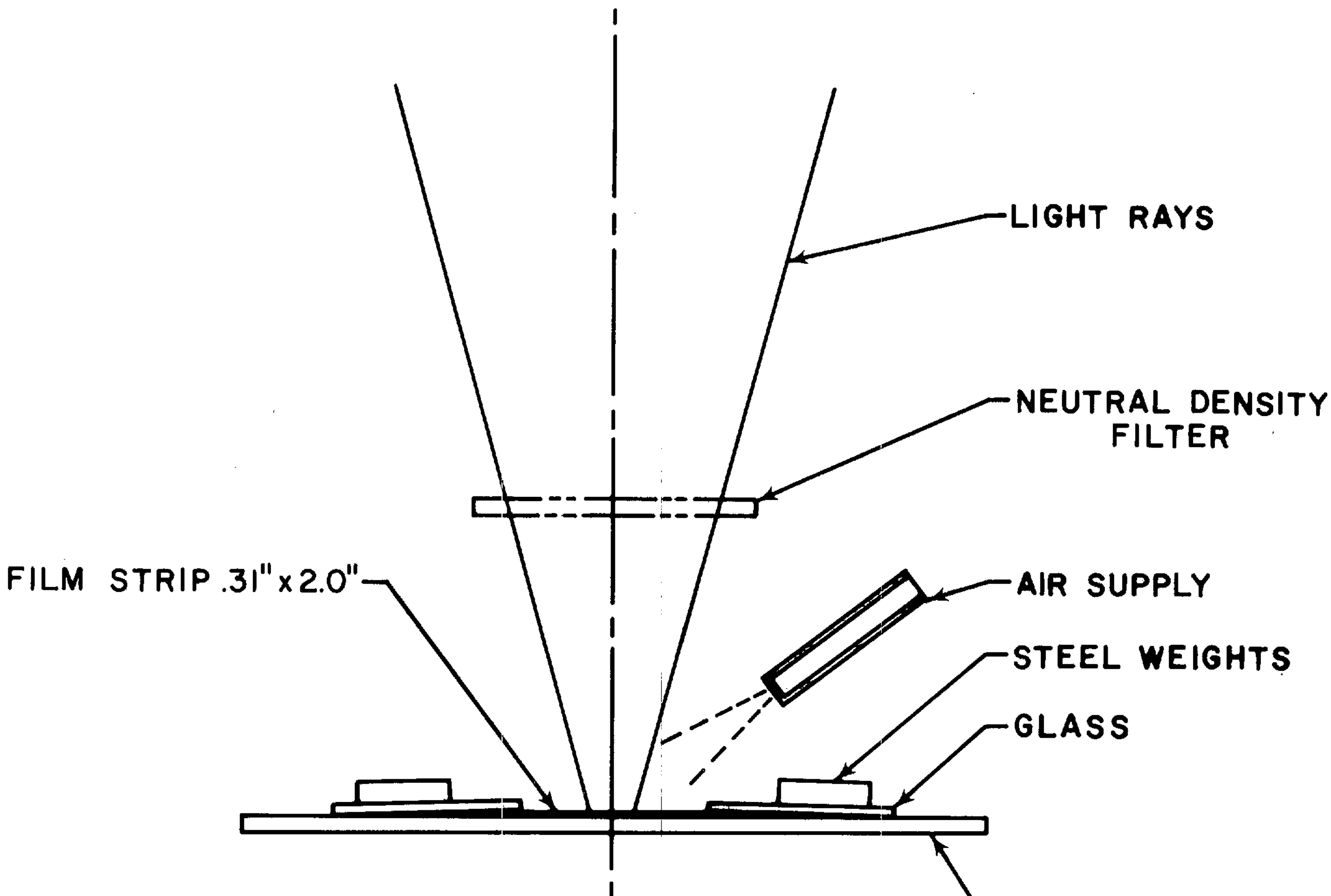
The fact that the measured attenuation through the filters does not quite match the theoretical is probably due to reflection losses at the glass-air surfaces of the filters. This merely demonstrates once again the necessity of making direct measurements at the film plane.

With the illumination system calibrated, the film stability tests were set up as shown in Figure 3. The test film strip was produced by contact printing from a glass grid plate onto film supplied by the customer. The resulting film strip had clear lines on a black background (D = 2.0). The Gilliland measuring engine was used to detect any appreciable expansion of the film by successively measuring the distance between two grid intersections as the rate of cooling air flow was varied. Air flow variation was achieved by varying air supply pressure, or nozzle orifice size, or a combination of both. Since the pressure ratio across the orifice always exceeded the critical pressure ratio, the air flow through the orifice was always at the acoustic velocity, and this permits a rather straightforward calculation of the weight flow rate. By varying



CALORIMETER TEST SETUP

FIGURE 2



FILM STABILITY TEST SETUP

FIGURE 3

the flow rate from a maximum down to the point where a film expansion could be detected, the minimum acceptable flow rate for each heating condition was determined.

Flow through a "choked" orifice can be determined from the equation:

$$G = \sqrt{\frac{gk}{R}\left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}} \quad \frac{A_2 P_1}{\sqrt{T_1}}$$

where:

G = flow rate in #/sec
g = 32.2 ft/sec^2
R = gas constant - 53.3
k = adiabatic coefficient - 1.4 for air
A_2 = orifice area - ft^2
p_1 = upstream pressure - #/ft^2
T_1 = upstream temperature - °R

For air this becomes:

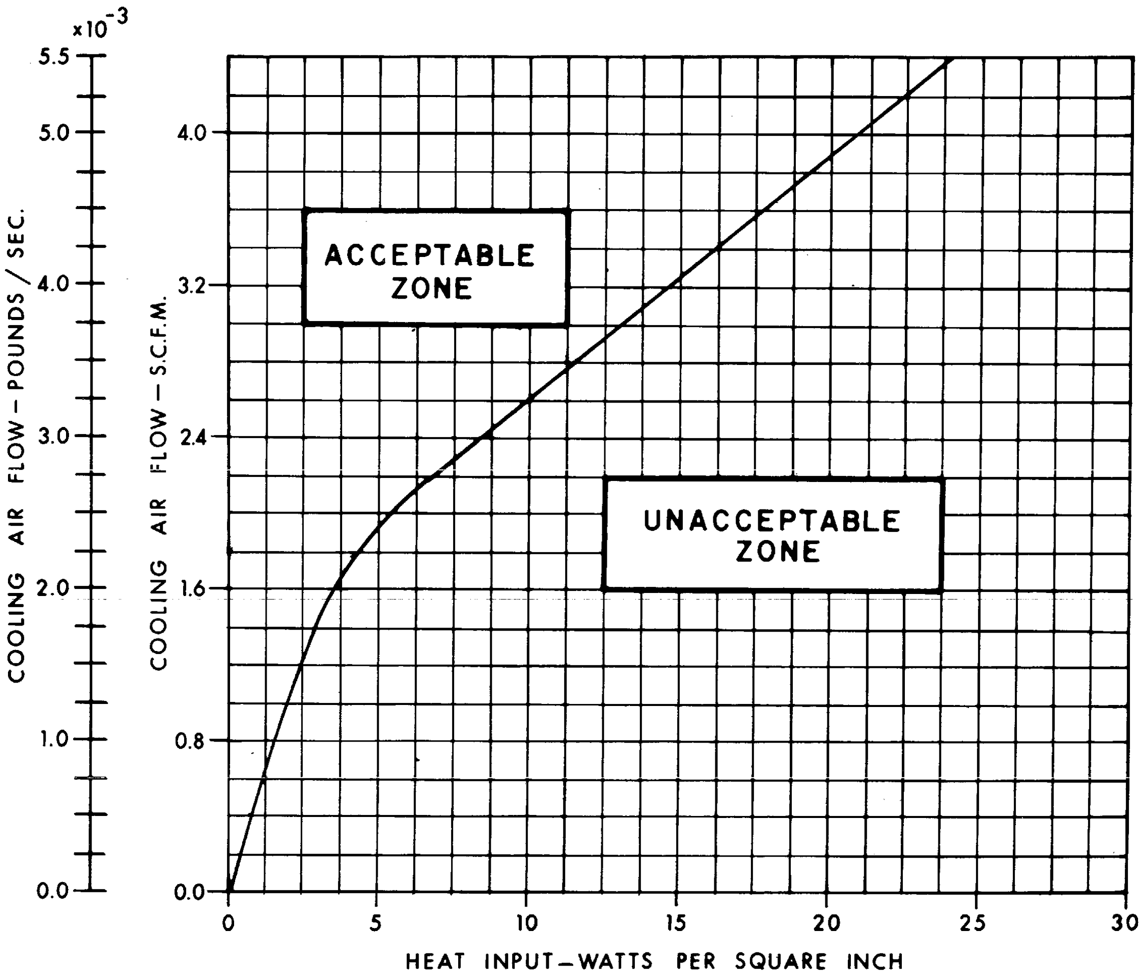
$$G = 0.532 \quad \frac{A_2 P_1}{\sqrt{T_1}}$$

For the air supply equipment set up for these tests, the entire process can be considered adiabatic, since the air supply storage tank was not sufficiently large to allow any appreciable heat transfer. Thus, the upstream temperature was calculated under the assumption of adiabatic compression to the pressure p_1. Flow rates were then calculated from the known orifice areas and pressures. Figure 4 is a plot showing the minimum flow rate for acceptable cooling versus the heat input. It is interesting to note that there is a break in the curve at about 2 standard cubic feet per minute and 5 watts per square inch, indicating more efficient cooling at the higher air velocities. Above this break point, there is a linear relationship between the cooling flow rate and the heat input. This should allow for a reasonable amount of extrapolation to higher heat inputs in the new instruments. This linear relationship also agrees with heat transfer theory for turbulent flow, which predicts a heat transfer coefficient linearly related to the fluid velocity.

3. RECOMMENDATION

In using these experimental data for instrument design, one should remember that the curve of figure 4 represents the minimum allowable cooling for safe operation in the measuring engine. A prudent designer would probably include a safety factor of 1.5 to 2.0 in his equipment.

Another important point to be considered in cooling system design is that the temperature of the air as it strikes the film should be very near the room ambient temperature. This will prevent sub-cooling in the case where the flow rate is greater than that actually required.



MINIMUM COOLING VS. HEAT INPUT

FIGURE 4